(54) **METHOD FOR DRIVING STEPPING MOTOR OF MULTIPHASE HYBRID TYPE.**

(57) A motor improved in the torque stiffness, and reduced in the resonance vibration when the motor rotates. The fixed magnetic poles each have two or more small teeth which are arranged at the same interval as the tooth pitch of the rotor. The total number (NS) of small teeth of the stators of an asymmetrical type is determined by NS = 5 x (n0 + n1) (where n0 is the number of small teeth of each of five fixed magnetic poles, and n1 is the number of small teeth of the other five fixed magnetic poles). The stators of asymmetrical type having n1 small teeth are arranged between the stators of asymmetrical type having n0 small teeth. The stators of asymmetrical type having the n0 small teeth are arranged on the side opposite to the stators of asymmetrical type having n1 small teeth across the shaft, respectively. In the winding wound on the asymmetric stator, N and S poles are generated. In both full-step and half-step modes, the numbers of the N and S poles are equal because of the magnetization of the poles in each step. In all the steps there are a pair or more of S poles which are adjacent to each other.

EP 0 635 929 A1

Fig. 3
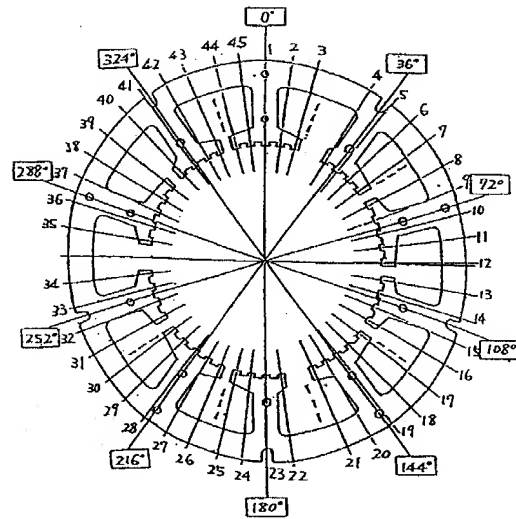
STRUCTURE OF ASYMMETRIC STATOR

shift angle 1/5 Tp., and Nr = 50 Ns = 45
small slot having three intervals
small slot having seven intervals

PRIOR ART

The present invention relates to an improved method of driving a 5-phase hybrid stepping motor.

BACKGROUND OF THE INVENTION

Hybrid stepping motors have been well known for over a quarter of the century as actuators appropriated for highly accurate positioning movements. The hybrid stepping motors are widely used in various machine tools, e.g. with fully automated production lines, as well as computer related instruments including printers, plotters, facsimile machines, and disk drive units.

For increasing the versatility in use, there is made an attempt to minimize the step angle of such a hybrid stepping motor. To this respect, four- and five-phase types of the stepping motor are now commonly provided.

The conventional four- or five-phase stepping motors however have some disadvantages that torque stiffness is unstable, that static torque is varied depending on the stop position, and that the step angle is not at a high accuracy. It is an object of the present invention to eliminate the foregoing disadvantages.

SUMMARY OF THE INVENTION

For achievement of the above object, a method of driving a multi-phase hybrid type stepping motor which has a rotor provided with one or more permanent magnets magnetized in the rotating direction of a rotary shaft, according to the present invention, is characterized by a two pole caps mounted to both ends of the permanent magnet respectively, each the pole cap made of a soft magnetic material and having a plurality (NR) of teeth arranged at equal intervals on the circumferential surface thereof, the teeth of the two pole caps being displaced by 1/2 of the teeth pitch (1/2 Tp) from each other, a plurality of stator segments of an asymmetrical form disposed around the rotor, each the asymmetrical stator segment having ten fixed magnetic poles thereof extending inwardly and radially, each the fixed magnetic pole having a winding wound thereon with no taps and being provided with two or more small teeth arranged at equal intervals of the same pitch as the teeth of the rotor, the total number (NS) of the small teeth of the asymmetrical stator segment being determined by $NS = 5 \times (n0 + n1)$, where $n0$ is the number of the small teeth on each of five of the ten fixed magnetic poles and $n1$ is the number of the small teeth on each of the remaining five fixed magnetic poles, the fixed magnetic poles with the $n1$ small teeth being arranged alternate with the

fixed magnetic poles with the $n0$ small teeth, the $n1$ small teeth pole and the $n0$ small teeth pole being disposed opposite to each other about the axis of the rotary shaft, the relation between the total number (NR) of the teeth of the rotor and the total number (NS) of the small teeth of the stator segment being expressed by NS2420.8-NR (NS being greater than or equal to 0.8-NR), a difference between NR and NS being calculated from $NR-NS = K(S0-S1) + 10(S1-1 + B)$ where K is an integer from 2 to 5, S0 and S1 are smallest possible integers or may be equal, and B is a fraction of 1 so that 10B (ten times of B) is always an integer, the ten stator windings on their respective fixed magnetic poles being coupled to one another in a circular order of P3, P8, P5, P10, P7, P2, P9, P4, P1, and P6, five terminals disposed between P6 and P3, P8 and P5, P10 and P7, P2 and P9, and P4 and P1 respectively, and by polarization of the ten fixed magnetic poles at each step of the rotating movement, N and S poles of the same number being generated and one or more pairs of the adjacent fixed magnetic poles being turned to S.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross sectional view showing one embodiment of the present invention; Fig. 2 is a longitudinal sectional view of the embodiment of the present invention; Fig. 3 is a front view of a stator system another embodiment of the present invention; Fig. 4 is a vector diagram of a rotor in the embodiment of the present invention; Fig. 5 is a wiring diagram according to the embodiment of the present invention; Fig. 6 is a chart showing the magnetic shift at fixed magnetic poles in full-step mode; and Fig. 7 is a chart showing the magnetic shift at the fixed magnetic poles in half-step mode.

THE PREFERRED EMBODIMENTS OF THE PRESENT INVENTION

Preferred embodiments of the present invention will be described in more details referring to the accompanying drawings.

Figs. 1 and 2 illustrate in cross section a stepping motor according to the present invention. Fig. 1 is a cross sectional view taken along the line extending at a right angle to a rotary shaft 4. As shown, a stator 1 has ten fixed magnetic poles S, S' arranged inwardly thereof. The fixed magnetic pole S or S' has a stator coil 2 wound thereon and is provided at inward end with a set of small teeth 3. It is assumed that the total number of the small teeth 3 is NS. The rotary shaft 4 has a rotor 5 mounted at center thereto. The rotor 5 has a permanent magnet 7 mounted to the axial center thereof and two rotor caps 8 fitted to both sides of

the magnet 7 respectively, as best shown in Fig. 2. The rotor caps 8 have a plurality of teeth 6 provided on the circumferential surface thereof. It is now assumed that the total number of the teeth 6 is NR. Fig. 1 is a cross sectional view taken along the line A-A of Fig. 2. The ten stator coils 2 are numbered from P1 to P10.

A first embodiment of the present invention is intended to have a five-phase stepping motor with the ten fixed magnetic poles S, S' improved in the torque stiffness, the step angle precision, and the efficiency of movement when NR=50 (where a shift angle between two adjacent fixed magnetic poles is 1/5Tp, Tp being a pitch of the small teeth 3) . In particular, the number of the small teeth 3 of each alternate one of the ten fixed magnetic poles is increased by one while that of the other fixed magnetic poles is kept 4 (forming an asymmetrical fixed magnetic pole arrangement of the stator). Accordingly, the 4-teeth fixed magnetic pole S is disposed opposite to the 5-teeth fixed magnetic pole S' (Fig. 3).

The difference of the teeth between the rotor 5 and the fixed magnetic poles S,S' is 5 (as calculated by subtracting 4x5 from 50 and then, 5x5 from the result).

This embodiment also offers an improvement in the stability at torque equilibrium position. The reason is that while at least two adjacent fixed magnetic poles are polarized to N, other two adjacent fixed magnetic poles are turned to S (Fig. 6).

As compared with the first embodiment in which the improvement in the four different respects is ensured with the rotor having 40, 50, 80, 90, or 100 of the teeth, using such an asymmetrical arrangement of the ten fixed magnetic poles of the stator, a second embodiment is characterized by the shift angle between two adjacent fixed magnetic poles which is equal to 3/10 Tp or 7/10 Tp. Equally, the number of the small teeth 3 of every alternate one of the fixed magnetic poles is increased by one.

For determining an optimum degree of the step angle for performance of a stepping motor, the difference of teeth between the rotor and the stator is preferably 5 or 3.

As shown in Fig. 4, a radial stress exerted on the rotor caps is divided into three directions. The stress is evenly applied to the two rotor caps. The three directional components of the stress may less affect the manufacturing tolerance. Thereby, the step angle accuracy will increase and unwanted vibration will be reduced. This is because there are provided only three large distanced slots between the fixed magnetic poles. Fig. 6 shows the polarization of the fixed magnetic poles during a series of 20 consecutive steps. The full 20 steps perform one rotation of the rotary shaft 4. As apparent from

Fig. 6, the number of N poles is identical to the number of S poles in the stepping motor at every position or step. This results in reduction of the hysteresis.

The step-by-step rotating movement will now be described referring to Figs. 5 and 6. Fig. 5 is a wiring diagram according to the embodiment of the present invention. The ten fixed magnetic poles are coupled to one another in a circular order of P3, P8, P5, P10, P7, P2, P9, P4, P1, and P6. Five, blue, red, orange, green, and black colored, terminals are provided between P6 and P3, P8 and P5, P10 and P7, P2 and P9, and P4 and P1 respectively. Fig. 6 is a diagram showing the polarization of the fixed magnetic poles in a full step mode. The dots in Fig. 5 represent the direction of coil windings.

Each of the blue, red, orange, green, and black colored terminals is coupled to a two-throw switch which normally stays in the neutral mode and is turned to one position for connecting to a positive source and to the other position for connecting to a negative source, although its switching circuit is not shown in Fig. 5. The switch is selectively connected to one of the three positions by a command signal from an unshown control unit. Accordingly, the ten magnetic poles are energized to have polarities as shown in Fig. 6 at each step. The switching action at the step produces the two polar states of the same number where at least two adjacent magnetic poles are polarized to S.

Fig. 7 is a diagram showing the polarization of the fixed magnetic poles at the steps in a half step mode.

As set forth above, the present invention with the foregoing arrangement allows the torque stiffness to be stable, the static torque to be equilibrated, and the step angle to be at high accuracy. In the full step mode, the S and N poles of the same number are produced and also, at least two adjacent fixed magnetic poles are polarized to S at each step of the movement. This will minimize abnormal vibration during the rotating movement.

APPLICABILITY TO INDUSTRIAL USE

As the specific teeth arrangements of the rotor and the stator are provided in a combination, the static torque acts in equilibrium and the step angle stays at high accuracy. In addition, the S and N poles become equal in the number in both the full and half step modes, abnormal vibration during the rotating movement will be minimized.

Claims

1. A method of driving a multi-phase hybrid type stepping motor which has a rotor provided with

one or more permanent magnets magnetized
in the rotating direction of a rotary shaft, char-
acterized by a two pole caps mounted to both
ends of the permanent magnet respectively,
each the pole cap made of a soft magnetic
material and having a plurality (NR) of teeth
arranged at equal intervals on the circumferen-
tial surface thereof, the teeth of the two pole
caps being displaced by 1/2 of the teeth pitch
(1/2 Tp) from each other, a plurality of stator
segments of an asymmetrical form disposed
around the rotor, each the asymmetrical stator
segment having ten fixed magnetic poles
thereof extending inwardly and radially, each
the fixed magnetic pole having a winding
wound thereon with no taps and being pro-
vided with two or more small teeth arranged at
equal intervals of the same pitch as of the
teeth of the rotor, the total number (NS) of the
small teeth of the asymmetrical stator segment
being determined by $NS = 5 \times (n0 + n1)$, where
n0 is the number of the small teeth on each of
five of the ten fixed magnetic poles and n1 is
the number of the small teeth on each of the
remaining five fixed magnetic poles, the fixed
magnetic poles with the n1 small teeth being
arranged alternate with the fixed magnetic
poles with the n0 small teeth, the n1 small
teeth pole and the n0 small teeth pole being
disposed opposite to each other about the axis
of the rotary shaft, the relation between the
total number (NR) of the teeth of the rotor and
the total number (NS) of the small teeth of the
stator segment being expressed by NS2420.8-
NR (NS being greater than or equal to 0.8-
NR), a difference between NR and NS being
calculated from $NR-NS = K(S0-S1) + 10(S1-1 + B)$ where K is an integer from 2 to 5, S0
and S1 are smallest possible integers or may
be equal, and B is a fraction of 1 so that 10B
(ten times of B) is always an integer, the ten
stator windings on their respective fixed mag-
netic poles being coupled to one another in a
circular order of P3, P8, P5, P10, P7, P2, P9,
P4, P1, and P6, five terminals disposed be-
tween P6 and P3, P8 and P5, P10 and P7, P2
and P9, and P4 and P1 respectively, and by
polarization of the ten fixed magnetic poles at
each step of the rotating movement, N and S
poles of the same number being generated
and one or more pairs of the adjacent fixed
magnetic poles being turned to S.

Fig. 1

Fig. 2
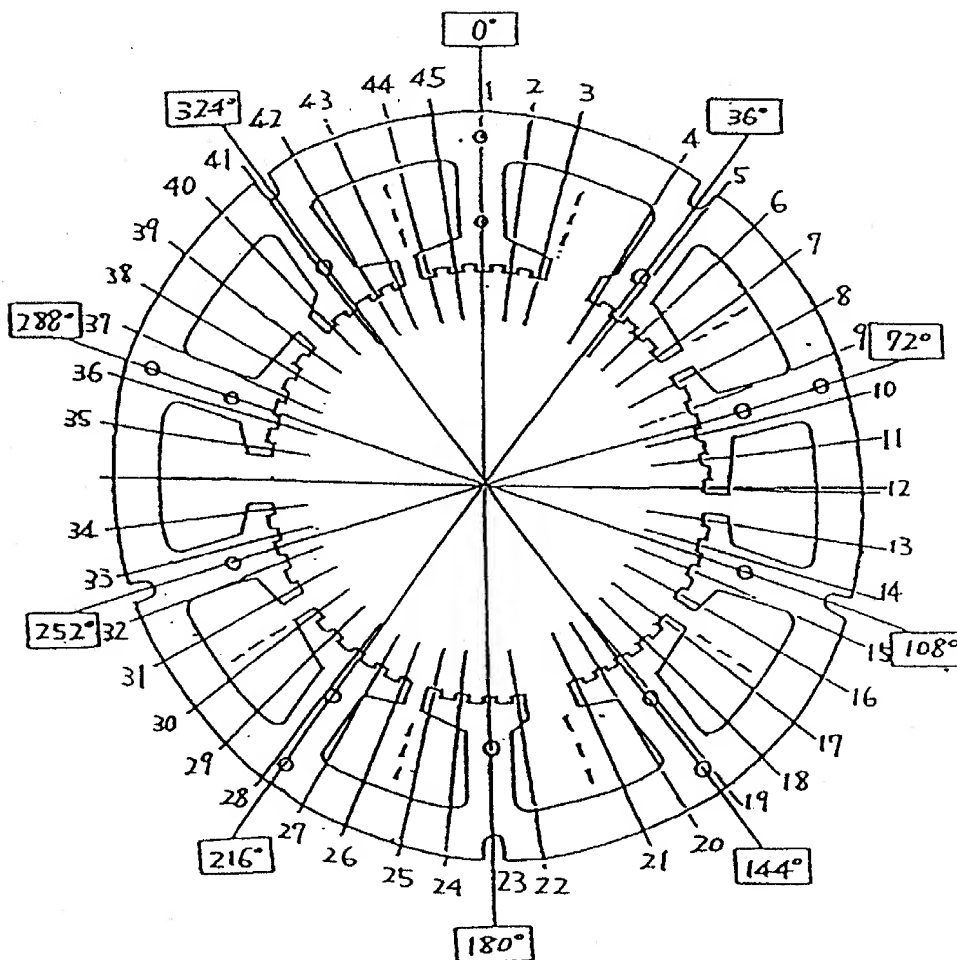
magnetic bundle passage

stator(1)

stator coil(2)

rotor(5)

A

A

N   S

(4)

(8)

rotor cap(8)

teeth(6)

small teeth(3)

(7)

A'
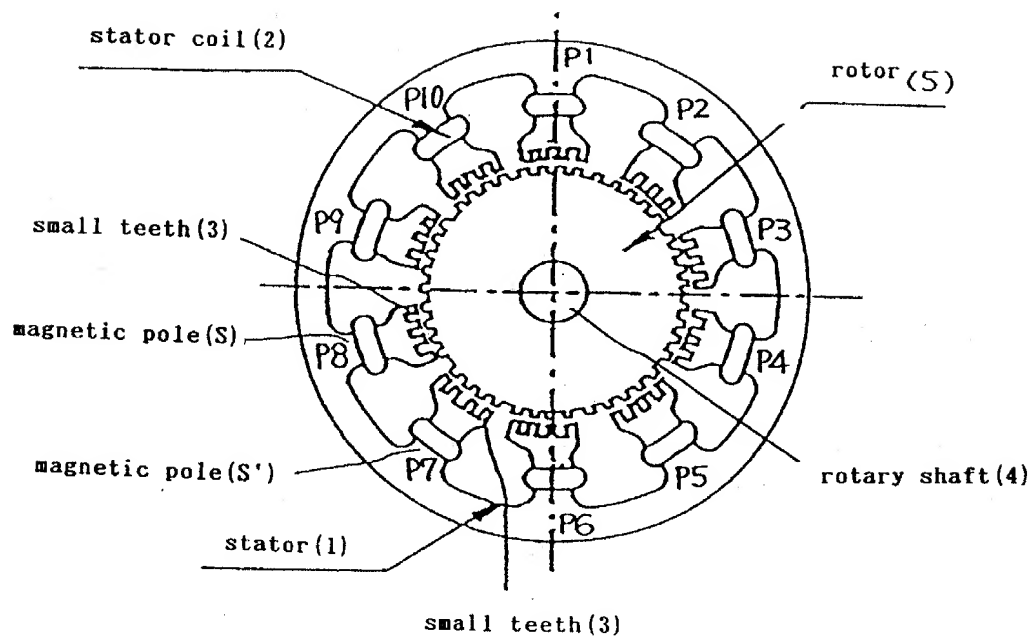
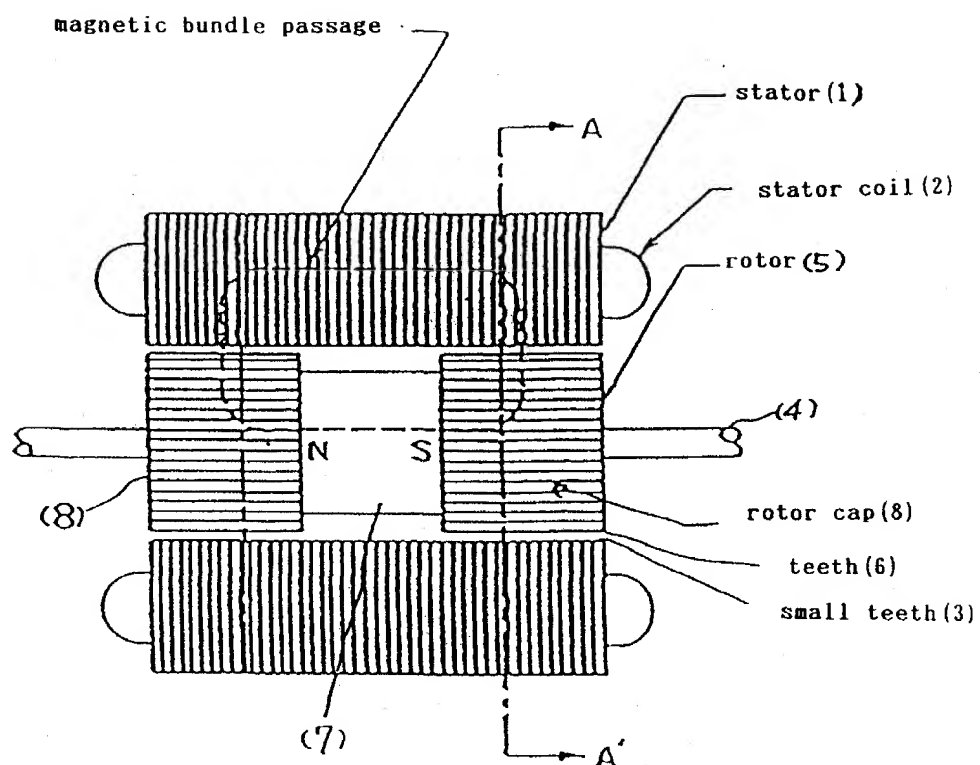# Fig. 3

STRUCTURE OF ASYMMETRIC STATOR

shift angle 1/5 Tp., and Nr = 50 Ns = 45
small slot having three intervals
small slot having seven intervals

Fig. 4

rotor of N pole

$P_{XN} = P_2 \,\hat{+}\, P_3$

P_{X_N}

P_{10}

P_2

P_9

P_3

P_6

rotor of S pole

P_1

P_8

P_4

P_7

P_5

$\vec{P}_{X_S} = P_8 \,\hat{+}\, P_7$

P_{X_S}

9

Fig. 5

Fig. 6

STEP \ POLE	1	2	3	4	5	6	7	8	9	10
1	–	S	N	N	S	–	N	S	S	N
2	N	S	–	N	S	S	N	–	S	N
3	N	S	S	N	–	S	N	N	S	–
4	N	–	S	N	N	S	–	N	S	S
5	N	N	S	–	N	S	S	N	–	S
6	–	N	S	S	N	–	S	N	N	S
7	S	N	–	S	N	N	S	–	N	S
8	S	N	N	S	–	N	S	S	N	–
9	S	–	N	S	S	N	–	S	N	N
10	S	S	N	–	S	N	N	S	–	N

Fig. 7
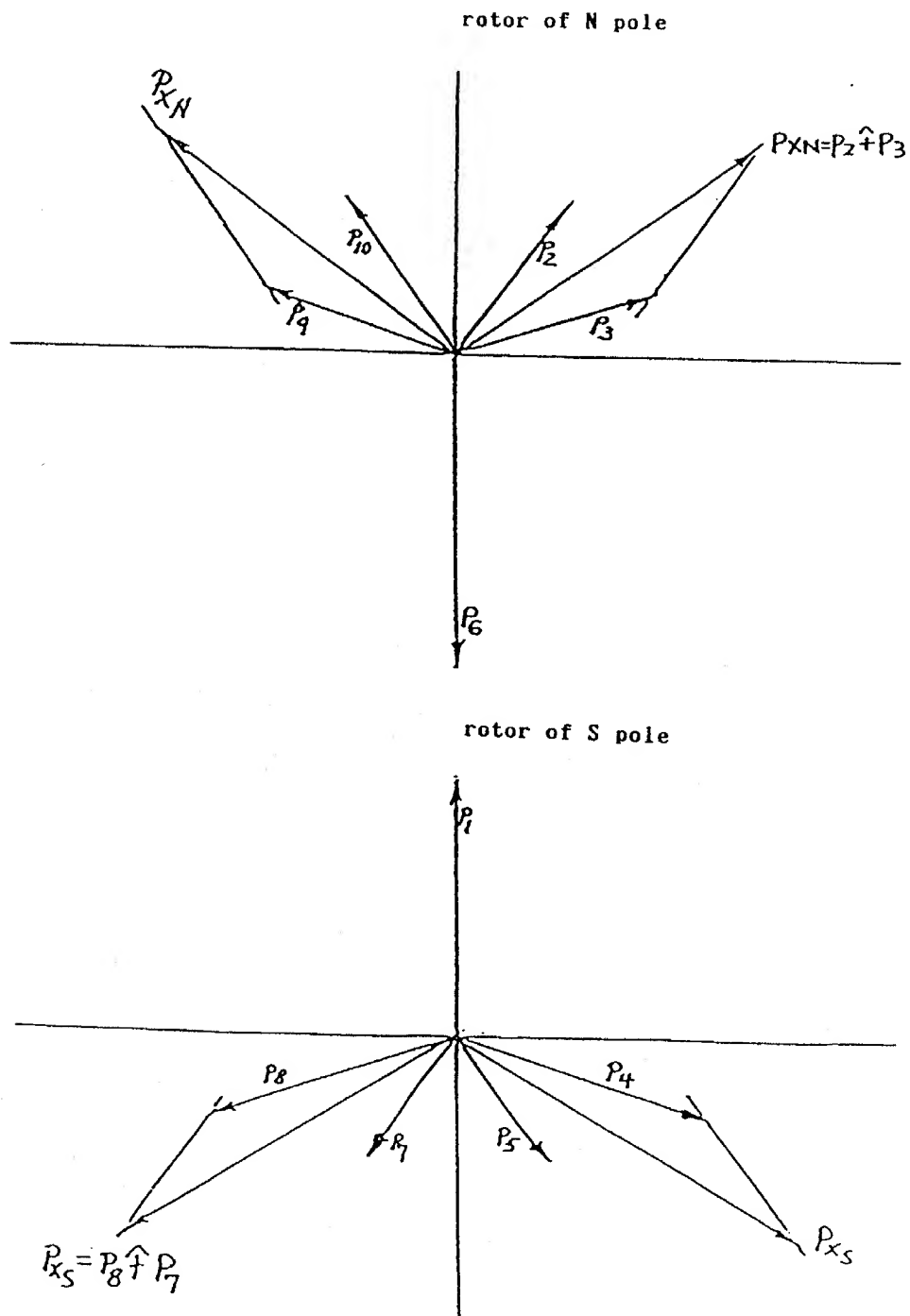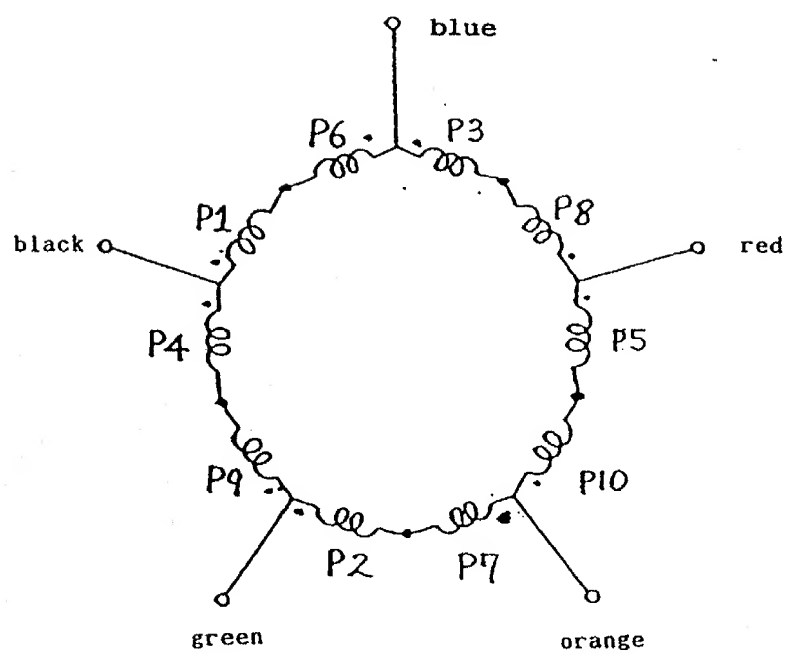
POLE STEP	1	2	3	4	5	6	7	8	9	10
1	S	S	N	N	S	N	N	S	S	N
2	-	S	N	N	S	-	N	S	S	N
3	N	S	N	N	S	S	N	S	S	N
4	N	S	-	N	S	S	N	-	S	N
5	N	S	S	N	S	S	N	N	S	N
6	N	S	S	N	-	S	N	N	S	-
7	N	S	S	N	N	S	N	N	S	S
8	N	-	S	N	N	S	-	N	S	S
9	N	N	S	N	N	S	S	N	S	S
10	N	N	S	-	N	S	S	N	-	S
11	N	N	S	S	N	S	S	N	N	S
12	-	N	S	S	N	-	S	N	N	S
13	S	N	S	S	N	N	S	N	N	S
14	S	N	-	S	N	N	S	-	N	S
15	S	N	N	S	N	N	S	S	N	S
16	S	N	N	S	-	N	S	S	N	-
17	S	N	N	S	S	N	S	S	N	N
18	S	-	N	S	S	N	-	S	N	N
19	S	S	N	S	S	N	N	S	N	N
20	S	S	N	-	S	N	N	S	-	N

INTERNATIONAL SEARCH REPORT

A.	CLASSIFICATION OF SUBJECT MATTER

Int. Cl⁵ H02K37/04

According to International Patent Classification (IPC) or to both national classification and IPC

B.	FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl⁵ H02K37/04, H02K37/00, H02K37/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926 - 1994
Kokai Jitsuyo Shinan Koho	1971 - 1994

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C.	DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, B2, 1-32748 (Oriental Motor Co., Ltd.), July 10, 1989 (10. 07. 89), Tables 2, 5, Figs. 1, 6 & US, A, 4385247	1
Y	JP, A, 61-185056 (Merck Japan Ltd.), August 18, 1986 (18. 08. 86), Figs. 2, 6, (Family: none)	1
Y	JP, U, 60-111382 (Mitsuba Electric Mfg. Co., Ltd.), July 27, 1985 (27. 07. 85), Fig. 1(b), (Family: none)	1

☑ Further documents are listed in the continuation of Box C.　　☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier document but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
May 27, 1994 (27. 05. 94)	June 14, 1994 (14. 06. 94)

Name and mailing address of the ISA/	Authorized officer
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